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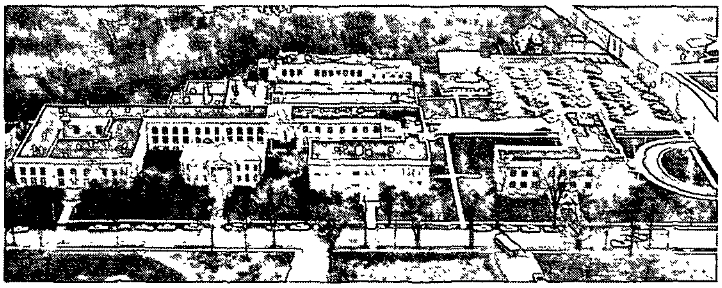

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ROUGHNESS ANISOTROPY IN PAPER

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ABSTRACT

The average or root mean square (rms) surface roughness of paper was measured using a stylus-type profilometer. Measurements in the machine direction (MD) and cross machine direction (CD) gave different roughness values. The roughness anisotropy, R_a, defined as R_{md}/R_{cd}, varies from about one to 1.6 and is greatest on the felt side of the paper. R_a increases with increasing levels of fiber orientation and MD wet straining of the sheet but is insensitive to the level of wet pressing pressure.

INTRODUCTION

The surface characteristics of paper are important in all grades that will be coated, printed, or laminated. Typically a "smooth" sheet is sought. This might be obtained by proper selection of furnish, paper making conditions, felt selection, calendering, or supercalendering. Most often paper smoothness (or roughness) is measured by one of a number of air leak methods. Such measurements are simple to carry out but suffer from a number of problems such as errors due to the porosity of the sheet or readings changing with changing pressure on the paper. Such measurements probably work best in rather narrow ranges of paper surface smoothness.

Stylus-type instruments are typically used in measuring the surface roughness of other engineering materials. In these devices a stylus with a small radius tip is pulled or pushed across the surface to be characterized and the vertical displacement of the stylus monitored with appropriate transducers. Such measurements have been made in paper (1-3). There are problems in applying these methods to paper because of the low stiffness of paper in the thickness direction. The local stress of the stylus could deform the paper, leading to erroneous results. In addition, the radius of the stylus determines the "quality" of the measurement. One could argue that in the case of paper it is not really possible to define a "surface" as we do for nonporous materials, since in paper the surface may actually go from one side of the paper to the other. These same difficulties also enter into the measurement of paper thickness (4).

This paper describes the surface roughness of paper as measured using a modern stylus-type instrument and describes how the roughness differs in the MD and CD as functions of paper machine operating variables.

EXPERIMENTAL

The surface analyzer used in this work was a Federal Products Surfanalyzer 4000. This device has a stylus tip radius of 100 microinches, with precisions in the horizontal and vertical positions of 6.1 and 50 microinches, respectively. The instrument had a digital output via a RS-232 serial port. Software was developed to collect information from the surface analyzer, convert it from hexadecimal to digital format, check for data errors, and save it in a binary file for later data processing. Data processing software was written to provide a number of smoothness characteristics, including the average roughness, R_A, the root mean square roughness, R_{RMS}, the mean cube root roughness, RC, and the frequency and size of voids and segments in the profilometer trace. Voids are the areas of the measured surface profile that lie below the algebraic center line of the trace, and segments are the lengths along the center line between voids.

R_A and R_{RMS} are defined as

$$R_A = (1/L) \int | z | dx \quad \text{and}$$
$$R_{RMS} = [(1/L) \int z^2 dx]^{1/2},$$

where L is the scan length, x is the position along the profile, and z is the vertical coordinate of the profile, measured from the (algebraic) center line of the profile. Both R_A and R_{RMS} are widely used to characterize rough surfaces (5). R_{RMS} is the standard deviation of the surface height distribution and is more sensitive to large deviations from the mean line than R_A. For the results presented here, only the traditional RMS roughness results are discussed. For a description of the other statistics the interested reader is referred to reference 6.

The profilometer digital output has a dynamic range of 4,096 bits, with each bit representing 6.104 microinches. Thus the maximum vertical displacement is 0.25 inch. The horizontal position of the stylus is determined by multiplying the number of sample points times the distance between points. The latter is the ratio of drive speed (0.01 or 0.1 in/s) to sampling rate. Scan lengths typically ranged from 0.5 to 0.75 inch.

The paper samples used for the work reported here were from an earlier study (7). They were softwood kraft sheets prepared on an anisotropic sheet former with different levels of fiber orientation, and were wet pressed, wet strained, and dried under various conditions. Table I lists the preparation conditions and gives the MD/CD elastic stiffness anisotropy ratio for each sample. Surface profiles were obtained in the MD and CD on both felt and wire sides. Six traces were made for each direction or side.

When surface profile measurements are made in a soft material like paper, there is the possibility of damage, caused by the stylus cutting or tearing the paper surface as it is pulled across (3). The stylus force was 1.96 mN. Assuming that this was applied over the entire circular cross section of the stylus, a local pressure of 96.7 GPa (1.4x10 4 lb/in^2) results. To see if such pressures did, in fact, damage the surface, scanning electron photomicrographs were made in the scanned area. No evidence of damage was apparent in any of the SEM's.

RESULTS AND DISCUSSION

Table II presents the RMS roughness values as wet straining and fiber orientation are varied, at constant wet pressing pressure. The upper left corner of Table II gives the RMS values in the MD and CD as measured on the wire side of the sheet for the low wet straining (WS) situation. The effect of increasing

TABLE I

Experimental Sheets

Sample	FO	WP	WS	E_{MD}/E_{CD}
259	L	L	L	1.69
248	L	M	L	1.63
257	L	H	L	1.68
260	L	M	H	2.51
268	H	M	L	3.43
269	H	M	H	5.86

FO = fiber orientation, WP = wet pressing, and WS = wet straining. For wet pressing the L, M, and H values are 27, 53, and 89 psi, respectively. For wet straining the L and H values are 0 and 2.4%, respectively.

fiber orientation from low to high (FO-L to FO-H) causes a 17% increase in the roughness anisotropy RA, defined as the ratio of the MD and CD RMS roughness values. The upper right corner shows the data for the felt side of the sheet. The results are similar to those for the wire side. The RA is about 1.25 for either side of the sheet at low wet straining and high fiber orientation. The lower half of Table II gives the situation for high wet straining levels. At

TABLE II

RMS Roughness and Machine Variables at Medium Wet Pressing

	Wire Side			Felt Side		
	R-MD, μin	R-CD, μin	RA	R-MD, μin	R-CD, μin	RA
Low Wet Straining:						
FO-L	209	195	1.07	208	180	1.17
FO-H	210	168	1.25	219	178	1.23
Change, %	0	-14	+17	+5	-1	+6
High Wet Straining:						
FO-L	206	212	0.97	203	174	1.17
FO-H	243	197	1.33	226	156	1.45
Change, %	+18	-7	+37	+11	-10	+24

FO = fiber orientation, L = low, H = high, R = RMS roughness; RA = roughness anisotropy (= R-MD/R-CD).

low fiber orientation levels the results are similar to those for the low WS and low FO case. However, for high WS and high FO, the differences between MD and CD roughnesses give RA values of 1.33 on the wire side and 1.45 on the felt side. According to Table II, the effect of increasing MD fiber orientation on surface roughness is to increase MD roughness and to decrease CD roughness. The differences are more pronounced with increased wet straining. Wet straining by itself, at low FO levels, has little or no effect on roughness anisotropy.

Table III shows the RMS roughness values as wet pressing pressure is changed, at constant (low) levels of FO and WS. There appears to be no effect of pressing pressure on roughness or on roughness anisotropy. This is probably a consequence of pressing all three sheets against the same felt. Table III again shows that the surface anisotropy is greatest on the felt side of the sheet. It would be anticipated that changing the pressing or dryer felts could change the overall magnitude of the surface roughness but probably not the anisotropy in the surface roughness. Calendering or supercalendering would presumably level out differences between MD and CD roughness, but this was not studied.

TABLE III

RMS Roughness *vs.* Wet Pressing
at Low Fiber Orientation and Low Wet Straining

	Wire Side			Felt Side		
Wet Press	R-MD, μin	R-CD, μin	RA	R-MD, μin	R-CD, μin	RA
Low	216	206	1.05	218	183	1.19
Medium	209	195	1.07	208	180	1.16
High	202	200	1.01	205	180	1.14
Change, %	-6	-3	-4	-6	-2	-4

R = RMS roughness, RA = roughness anisotropy (= R-MD/R-CD).

The results presented in Table II are for samples 248, 260, 268, and 269 (see Table I) and had elastic anisotropy ratios of 1.63, 2.51, 3.43, and 5.86, respectively. The corresponding surface roughness anisotropy ratios are 1.17, 1.17, 1.23, and 1.45 (felt side). Surface roughness anisotropy values measured on commercial papers range from 0.7 to 1.1 for silicone release, one time carbonizing, MF, and MG papers, and around 1.6 for kraft sack papers. It is quite likely that large differences between the MD and CD could give problems during printing or other converting operations involving the surface. It is important to realize that the surface roughness anisotropy seems to be related primarily to the level of fiber orientation in combination with wet straining. In grades where the sheet is not calendered, it may be possible to alter the smoothness by changes in these variables.

The conclusions based on Tables II and III are supported by two-tailed t-tests at the 95% confidence level. Table IV gives the geometric mean values (the square root of R-MD times R-CD) for the results shown in Tables II and III. These numbers should be related to the traditional air leak smoothness results, which also average over MD and CD directions. Table IV shows, in general, that the felt side is less rough than the wire side. Again, wet pressing pressure seems to have little effect, except possibly at very low levels. On the felt side of the sheets, the least rough samples are those that were highly wet strained, whereas the wire side of these same sheets are among the roughest. This latter result would be the expected one if the wet straining model proposed elsewhere is correct (8). More experiments will be required to clarify this point.

TABLE IV*

Geometric Mean Roughness Values, in

	Wire Side	Felt Side
Low Wet Strain		
FO-L	202	193
FO-H	188	197
High Wet Strain		
FO-L	209	188
FO-H	219	188
Low Wet Strain and FO-L		
Low WP	211	200
Medium WP	202	193
High WP	201	192

*Based on results presented in Tables II and III. WP = wet pressing pressure.

CONCLUSIONS

Surface roughness is affected by machine process variables such as fiber orientation and wet straining. Together these can produce a surface roughness anisotropy as large as 1.5. The anisotropy is largest on the felt side of the sheet. It is not obvious how increasing MD fiber orientation increases MD roughness while decreasing CD roughness. It may be possible, however, to minimize the anisotropy effects if they are troublesome, by proper choice of machine operating conditions.

LITERATURE CITED

1. Cahierre, L., Papier, Carton et Cellulose 23(4):58(1974).

2. Setterholm, V. C., and W. L. James, Forest Product Laboratory Report 2130, September, 1958.

3. Murakami, K., R. Imamura, and T. Yamamoto, Japan Tappi 27(2):8(1973)

4. Wink, W. A., and G. A. Baum, Tappi 66(9):131(1983).

5. Thomas, T. R., Rough Surfaces, Longman Group Limited, Harlow, Essex, U.K., 1982.

6. Waterman, D. R., "The characterization of paper smoothness using a stylus type instrument", A190 Report, The Institute of Paper Chemistry, Appleton, WI, March 10, 1986.

7. Fleischman, E. H., "An investigation of the elastic and dielectric anisotropy of paper", Doctoral Dissertation. The Institute of Paper Chemistry, Appleton, WI, 1981.

8. Baum, G. A., K. Pers, D. R. Shepard, and T. R. Ave'lallemant, Tappi 67(5):100(1984).

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